

Appendix A

Considering Risks from Indirect Pathways

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A.1 What are “Indirect Risks”?

IWAIR assesses exposures by direct inhalation of a chemical. It is possible, however, that environmental contaminants can be transferred to other media resulting in an indirect exposure to the pollutant. The purpose of this section is to provide risk assessors with information on health risks that may result from volatile emissions other than from the inhalation pathway. An indirect pathway of exposure is when a chemical that is released into one medium (for example, air)

is subsequently transported to other media, such as water, soil, or food, to which a receptor is exposed. For example, chemical vapors that are released from a WMU and transported to an adjacent agricultural field may diffuse into vegetation, deposit on vegetation, or may be taken up by vegetation from the soil. Individuals who subsequently eat the produce from that field may be exposed to contaminants in their diet. Additional indirect exposures can occur through the ingestion of contaminated fish, or animal products, such as milk, beef, pork, poultry, and eggs.

Direct Pathways: An individual is directly exposed to the contaminated medium, such as air or groundwater, into which the chemical was released.

Indirect Pathways: An individual is indirectly exposed when a chemical that is released into one medium (for example, air), is subsequently transported to other media, such as water, soil, or food, to which the individual comes in contact.

Figure A-1 shows these pathways graphically. The arrows indicate the flow of pollutants through the pathways. Pollutants are released from a source, dispersed through the air, and deposited on crops, pastures, soil, and surface water. From there, they may be taken up into plants or animal tissues. Humans may then be exposed by ingesting soil (through hand-to-mouth contact), ingesting plant products, or ingesting animal products (including fish). Although not shown in Figure A-1, humans may also ingest groundwater and surface water as drinking water sources. Groundwater exposures are modeled by the Industrial Waste Management Evaluation Model (IWEM), and surface water sources of drinking water are presumed to be treated to remove contaminants.

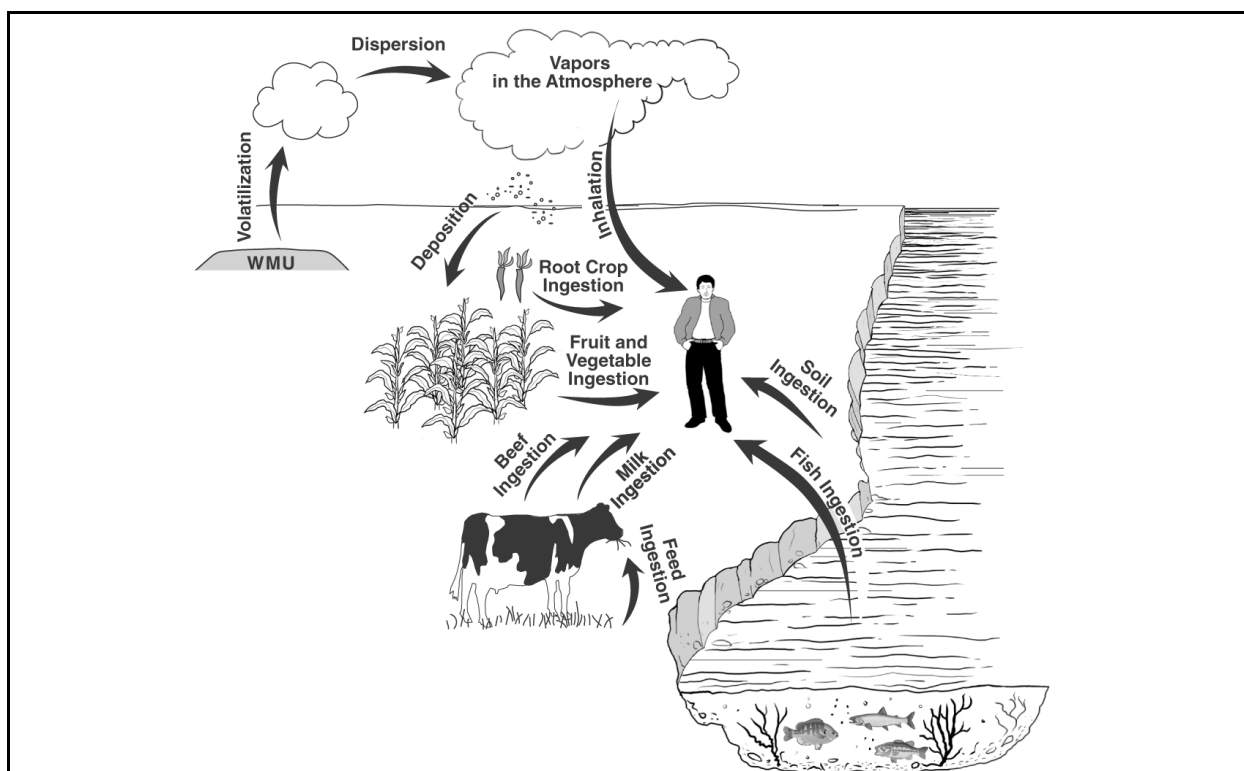


Figure A-1. Indirect exposure pathways.

A.2 Determining When Indirect Pathways May Be Important

There are two key factors a facility manager should consider when determining the need to assess the human health risk from indirect pathways of exposure. First, only certain land uses near a WMU may pose potential risks through indirect exposure pathways. Second, only certain chemicals may have properties that favor indirect pathways. These two criteria are explained in the following paragraphs.

A.2.1 Land Use

As described above, indirect exposures can occur when a vapor-phase constituent in the air is transported into surface water or taken up by produce or by animal products (via feed plants or surface water). However, these pathways are unlikely to be of concern unless the land use near the site includes one or more of the following:

- Residential home-gardening
- Agriculture (including production of produce and animal products for human consumption)
- Farms that grow feed for animals

- Recreational fishing
- Recreational hunting areas.

A.2.2 Chemical Properties

In addition to land use, the chemical properties of the constituents in the waste are important in determining whether indirect pathways are of potential concern. Some chemicals exhibit properties that tend to favor indirect pathways, while others do not, or do so to a lesser extent. The chemical properties of interest are those that reflect the tendency for a chemical to be persistent in the environment, bioaccumulate in plants or animals, or be toxic when ingested.¹ A facility manager should consider these properties when determining whether an assessment of indirect pathways may be necessary for the WMU. The following subsections provide a brief description of some of the chemical properties that can be used to predict a constituent's persistence, bioaccumulation potential, and toxicity.

Persistence

A chemical's persistence refers to how long the chemical remains in the environment without being chemically or biologically broken down or altered. A chemical considered to be highly persistent remains in the environment for a relatively long period of time, although it may move through different media (e.g., from soil to water to sediment). Because persistent chemicals remain in the environment, they can accumulate in environmental media and/or plant and animal tissue. As a result, the temporal window for exposure through both direct and indirect pathways may be extended, and the likelihood of exposure will increase. Persistence is frequently expressed in terms of half-life. For example, if a chemical has a half-life of 2 days, it will take 2 days for a given quantity of the chemical to be reduced by one-half due to chemical and biological processes. The longer the half-life, the more persistent the chemical. A related chemical property is degradation rate, which is inversely related to half-life. Thus, the lower the degradation rate, the more persistent the chemical. Data on soil biodegradation rates are presented for the IWAIR chemicals in Appendix B; this property may be used as a general indicator of persistence potential.

Bioaccumulation Potential

Bioaccumulation potential refers to a chemical's tendency to accumulate in plants and animals. For example, plants may accumulate chemicals from the soil through their roots. Some of these chemicals are transformed or combined with others and used by the plant; others are simply eliminated; and others accumulate in the plant roots, leaves, or edible parts of the plant. Animals also bioaccumulate certain chemicals in different tissues or organs. For chemicals that

¹ The tendency of chemical constituents to be persistent and bioaccumulate are a function of both the chemical/physical attributes of the chemical (e.g., K_{ow}) and the environmental setting (such as the physical characteristics of the system, e.g., dissolved organic carbon, soil pH; or the biology of organisms that inhabit the system, e.g., crops, fish species); however, it is convenient to think of persistence and bioaccumulation potential as intrinsic properties when considering indirect exposure pathways.

bioaccumulate, the concentration in the plants and animals can be higher than the concentration in the environment. As a result, a human who eats the plant or animal may be exposed to a higher concentration in the food than in the contaminated medium.² Bioaccumulation potential may be expressed as a bioaccumulation factor (BAF) or a bioconcentration factor (BCF); these factors express the relationship between the concentration in biota and the concentration in the environmental medium. Bioaccumulation potential may also be expressed as a biotransfer factor for animal products, representing the relationship between the exposure concentration and the mass of contaminated plants ingested daily.

Chemicals that tend to accumulate in plants and animal tissues often have a characteristically high affinity for lipids (fats). This tendency is reflected by the octanol-water partition coefficient (K_{ow}),³ a laboratory measurement of the attraction of a chemical to water versus its attraction to lipids (fats). In these experiments, octanol is used as a surrogate for lipids. Because chemicals with higher K_{ow} values have been shown to have a greater tendency to accumulate in the fatty tissue of animals, the BAF and BCF are generally accepted as useful predictors of bioaccumulation potential (see text box for definitions and examples of other parameters that are often used to evaluate indirect exposures through the ingestion of produce and animal products). Some chemicals with high K_{ow} values, such as polycyclic aromatic hydrocarbons (PAHs), do not accumulate appreciably in animals that have the capacity to metabolize the chemical and eliminate it from their systems. Moreover, this strong affinity for lipids also means that the chemical has a strong affinity for organic carbon in soil and surface water. Chemicals that are strongly sorbed to the organic component in soil may not be readily taken up by plants. For example, dioxin is poorly taken up from the soil by virtually all species of plants that have been tested.

Parameters Used to Evaluate Indirect Exposures

BCF: Bioconcentration Factor for Fish. Defined as the ratio of chemical concentration in the fish to the concentration in the surface water. Fish are exposed only to contaminated water.

BAF: Bioaccumulation Factor for Fish. Defined as the ratio of the chemical concentration in fish to the concentration in the surface water. Fish are exposed to contaminated water and plants/prey.

BSAF: Biota-Sediment Accumulation Factor for Fish. Generally applied only to highly hydrophobic organic chemicals, and defined as the ratio of the lipid-normalized concentration in fish to the organic carbon-normalized concentration in surface sediment. Fish are exposed to contaminated pore water, sediment, and plants/prey.

Br: Plant-Soil Bioconcentration Factor. Defined as the ratio between the chemical concentration in the plant and the concentration in soil. It varies by plant group (e.g., root vegetables, aboveground vegetables).

Bv: Air-Plant Bioconcentration Factor. Defined as the mass-based ratio between the chemical concentration in the plant and the vapor-phase chemical concentration in the air. It varies by plant group (e.g., leafy vegetables, forage).

Ba: Plant-Animal Biotransfer Factor. Defined as the ratio between the chemical concentration in the animal tissue and the amount of chemical ingested per day. It varies by type of animal tissue (e.g., beef, milk).

² Even though the concentration in food may not be significantly higher than in the environmental media, the consumption rate of produce and meat/dairy products may lead to a substantial exposure to contaminants.

³ Because octanol-water coefficients can span many orders of magnitude, they are normally discussed in terms of their log values ($\log K_{ow}$).

Consequently, the use of chemical properties should be supplemented with information from field studies to determine whether the chemical is of potential concern through indirect exposure pathways. Data on $\log K_{ow}$ are presented for the IWAIR chemicals in Appendix B; they may be used as a first-cut indicator of bioaccumulation potential. As a general rule, chemicals with relatively high K_{ow} values tend to accumulate in plants and animals to a greater extent than chemicals with relatively low K_{ow} values.

Toxicity

The toxicity of chemicals to humans depends on the route of exposure—inhalation or ingestion. IWAIR contains health benchmarks for inhalation exposures. However, the indirect pathways discussed here refer to ingestion exposures. Therefore, even if a chemical is released into the air and tends to bioaccumulate in plant or animal products, if it is not very toxic by the ingestion pathway, then indirect pathways will be of less concern. Two benchmarks are used to predict the toxicity of a chemical that is ingested: the cancer slope factor (CSF, which measures the tendency of a chemical to cause cancer) and the reference dose (RfD, which provides a threshold below which a chemical is unlikely to result in adverse, noncancer health effects). The CSF is a measure of carcinogenic potency; consequently, a *larger* value indicates greater toxicity. However, the RfD is a threshold at which adverse effects are not expected; therefore, a *smaller* value indicates greater toxicity.

Oral toxicity benchmarks are not used in IWAIR; therefore, for convenience, the oral toxicity benchmarks (oral CSF and RfD) are presented for the IWAIR chemicals in Table A-1.

A.3 Additional Information

Indirect risk assessments are often site-specific, require a significant amount of information about the area surrounding the WMU, and can be complex depending on the chemicals of concern. However, indirect pathways should not be overlooked as a potential source of risk if the chemical properties and surrounding land uses suggest potential risks through indirect exposures.

If it appears that indirect pathways may be of concern, *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions* (U.S. EPA, 1998b) presents guidance developed by the Agency for conducting indirect risk assessments for most chemicals. This document can be used to determine whether further assessment of indirect pathways is needed, and, if so, how to conduct such an assessment. For dioxin-like compounds, indirect pathways are evaluated somewhat differently; see U.S. EPA (2000a), *Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds. Part I: Estimating Exposure to Dioxin-Like Compounds*.

Table A-1. Oral Health Benchmarks for IWAIR Chemicals

IWAIR Constituent Name	CASRN	RfD (mg/kg-d)	RfD Source	CSFo (per mg/kg-d)	CSFo Source	Comment
1,1,1,2-Tetrachloroethane	630-20-6	3.0E-02	IRIS	2.6E-02	IRIS	
1,1,1-Trichloroethane	71-55-6	2.8E-01	SF			
1,1,2,2-Tetrachloroethane	79-34-5	6.0E-02	SF	2.0E-01	IRIS	
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	3.0E+01	IRIS			
1,1,2-Trichloroethane	79-00-5	4.0E-03	IRIS	5.7E-02	IRIS	
1,1-Dichloroethylene	75-35-4	9.0E-03	IRIS	6.0E-01	IRIS	
1,2,4-Trichlorobenzene	120-82-1	1.0E-02	IRIS			
1,2-Dibromo-3-chloropropane	96-12-8			1.4E+00	HEAST	intermediate MRL available
1,2-Dichloroethane	107-06-2			9.1E-02	IRIS	intermediate MRL available
1,2-Dichloropropane	78-87-5	9.0E-02	ATSDR	6.8E-02	HEAST	
1,2-Diphenylhydrazine	122-66-7			8.0E-01	IRIS	
1,2-Epoxybutane	106-88-7					
1,3-Butadiene	106-99-0					
1,4-Dioxane	123-91-1			1.1E-02	IRIS	
2,3,7,8-TCDD	1746-01-6	1.0E-09	ATSDR	1.5E+05	HEAST	
2,4-Dinitrotoluene	121-14-2	2.0E-03	IRIS	6.8E-01	IRIS	CSFo is for 2,4-/2,6- mixture
2-Chlorophenol	95-57-8	5.0E-03	IRIS			
2-Ethoxyethanol	110-80-5	4.0E-01	HEAST			
2-Ethoxyethanol acetate	111-15-9	3.0E-01	HEAST			
2-Methoxyethanol	109-86-4	1.0E-03	HEAST			
2-Methoxyethanol acetate	110-49-6	2.0E-03	HEAST			
2-Nitropropane	79-46-9					
3,4-Dimethylphenol	95-65-8	1.0E-03	IRIS			
3-Methylcholanthrene	56-49-5					
7,12-Dimethylbenz[a]anthracene	57-97-6					

(continued)

Table A-1. (continued)

IWAIR Constituent Name	CASRN	RfD (mg/kg-d)	RfD Source	CSFo (per mg/kg-d)	CSFo Source	Comment
Acetaldehyde	75-07-0					
Acetone	67-64-1	1.0E-01	IRIS			
Acetonitrile	75-05-8					
Acrolein	107-02-8	2.0E-02	HEAST			
Acrylamide	79-06-1	2.0E-04	IRIS	4.5E+00	IRIS	
Acrylic acid	79-10-7	5.0E-01	IRIS			
Acrylonitrile	107-13-1	1.0E-03	HEAST	5.4E-01	IRIS	
Allyl chloride	107-05-1					
Aniline	62-53-3			5.7E-03	IRIS	
Benzene	71-43-2			5.5E-02	IRIS	upper range estimate used for CSFo
Benzidine	92-87-5	3.0E-03	IRIS	2.3E+02	IRIS	
Benzo(a)pyrene	50-32-8			7.3E+00	IRIS	
Bromodichloromethane	75-27-4	2.0E-02	IRIS	6.2E-02	IRIS	
Carbon disulfide	75-15-0	1.0E-01	IRIS			
Carbon tetrachloride	56-23-5	7.0E-04	IRIS	1.3E-01	IRIS	
Chlorobenzene	108-90-7	2.0E-02	IRIS			
Chlorodibromomethane	124-48-1	2.0E-02	IRIS	8.4E-02	IRIS	
Chloroform	67-66-3	1.0E-02	IRIS			
Chloroprene	126-99-8	2.0E-02	HEAST			
cis-1,3-Dichloropropylene	10061-01-5	3.0E-02	IRIS	1.0E-01	IRIS	RfD & CSFo are for 1,3-dichloropropene
Cresols (total)	1319-77-3	5.0E-02	surr			RfD is for m-cresol
Cumene	98-82-8	1.0E-01	IRIS			
Cyclohexanol	108-93-0	1.7E-05	solvents			
Dichlorodifluoromethane	75-71-8	2.0E-01	IRIS			
Epichlorohydrin	106-89-8	2.0E-03	HEAST	9.9E-03	IRIS	

(continued)

Table A-1. (continued)

IWAIR Constituent Name	CASRN	RfD (mg/kg-d)	RfD Source	CSFo (per mg/kg-d)	CSFo Source	Comment
Ethylbenzene	100-41-4	1.0E-01	IRIS			
Ethylene dibromide	106-93-4			8.5E+01	IRIS	
Ethylene glycol	107-21-1	2.0E+00	IRIS			
Ethylene oxide	75-21-8			1.0E+00	HEAST	
Formaldehyde	50-00-0	2.0E-01	IRIS			
Furfural	98-01-1	3.0E-03	IRIS			
Hexachloro-1,3-butadiene	87-68-3	3.0E-04	SF	7.8E-02	IRIS	
Hexachlorobenzene	118-74-1	8.0E-04	IRIS	1.6E+00	IRIS	
Hexachlorocyclopentadiene	77-47-4	6.0E-03	IRIS			
Hexachloroethane	67-72-1	1.0E-03	IRIS	1.4E-02	IRIS	
Isophorone	78-59-1	2.0E-01	IRIS	9.5E-04	IRIS	
Mercury	7439-97-6	1.0E-04	surr			RfD is for methyl mercury
Methanol	67-56-1	5.0E-01	IRIS			
Methyl bromide	74-83-9	1.4E-03	IRIS			
Methyl chloride	74-87-3			1.3E-02	HEAST	
Methyl ethyl ketone	78-93-3	6.0E-01	IRIS			
Methyl isobutyl ketone	108-10-1	8.0E-02	HEAST			
Methyl methacrylate	80-62-6	1.4E+00	IRIS			
Methyl tert-butyl ether	1634-04-4					intermediate MRL available
Methylene chloride	75-09-2	6.0E-02	IRIS	7.5E-03	IRIS	
N,N-Dimethyl formamide	68-12-2	1.0E-01	HEAST			
Naphthalene	91-20-3	2.0E-02	IRIS			
n-Hexane	110-54-3	1.1E+01	SF			
Nitrobenzene	98-95-3	5.0E-04	IRIS			
N-Nitrosodiethylamine	55-18-5			1.5E+02	IRIS	
N-Nitrosodi-n-butylamine	924-16-3			5.4E+00	IRIS	

(continued)

Table A-1. (continued)

IWAIR Constituent Name	CASRN	RfD (mg/kg-d)	RfD Source	CSFo (per mg/kg-d)	CSFo Source	Comment
N-Nitrosopyrrolidine	930-55-2			2.1E+00	IRIS	
o-Dichlorobenzene	95-50-1	9.0E-02	IRIS			
o-Toluidine	95-53-4			2.4E-01	HEAST	
p-Dichlorobenzene	106-46-7			2.4E-02	HEAST	intermediate MRL available
Phenol	108-95-2	6.0E-01	IRIS			
Phthalic anhydride	85-44-9	2.0E+00	IRIS			
Propylene oxide	75-56-9			2.4E-01	IRIS	
Pyridine	110-86-1	1.0E-03	IRIS			
Styrene	100-42-5	2.0E-01	IRIS			
Tetrachloroethylene	127-18-4	1.0E-02	IRIS	5.2E-02	HAD	
Toluene	108-88-3	2.0E-01	IRIS			
trans-1,3-Dichloropropylene	10061-02-6	3.0E-02	IRIS	1.0E-01	IRIS	RfD & CSFo are for 1,3-dichloropropene
Tribromomethane	75-25-2	2.0E-02	IRIS	7.9E-03	IRIS	
Trichloroethylene	79-01-6			1.1E-02	HAD	
Trichlorofluoromethane	75-69-4	3.0E-01	IRIS			
Triethylamine	121-44-8					
Vinyl acetate	108-05-4	1.0E+00	HEAST			
Vinyl chloride	75-01-4	3.0E-03	IRIS	7.2E-01	IRIS	CSFo is for continuous adult exposure
Xylenes	1330-20-7	2.0E+00	IRIS			

^a Sources:

- ATSDR = ATSDR oral minimal risk levels (ATSDR, 2001)
- IRIS = Integrated Risk Information System (U.S. EPA, 2001)
- HEAST = Health Effects Assessment Summary Tables (U.S. EPA, 1997a)
- HAD = Health Assessment Document (U.S. EPA, 1986, 1987)
- SF = Superfund Risk Issue Paper (U.S. EPA, 1998c, 1999a, 1999b, 2000b)
- solvents = 63 FR 64371-0402 (U.S. EPA, 1998a)
- surr = surrogate

Finally, as noted above, various chemical properties indicative of the potential for indirect pathway concern are presented in Appendix B for IWAIR chemicals. For other chemicals, the following sources may be useful:

log K_{ow}

- EPA's Superfund Chemical Data Matrix (SCDM) (U.S. EPA, 1997b)
- The Merck Index (Budavari, 1996)
- The National Library of Medicine's Hazardous Substances Databank (HSDB), available on TOXNET (U.S. NLM, 2001)
- Syracuse Research Corporation's CHEMFATE database (SRC, 1999)
- CambridgeSoft.com's ChemFinder database (CambridgeSoft, 2001)
- Agency for Toxic Substances and Disease Registry (ATSDR) Toxicological Profiles (ATSDR, 2001)
- EPA's *Dioxin Reassessment* (U.S. EPA, 2000a)—for dioxins only

Half-life

- Howard et al. (1991)

Toxicity (in order of preference)

- Integrated Risk Information System (IRIS) (U.S. EPA, 2001)
- Superfund Technical Support Center Provisional Benchmarks (U.S. EPA, 1998c, 1999a, 1999b, 2000b)
- Health Effects Assessment Summary Tables (HEAST) (U.S. EPA, 1997a)
- Agency for Toxic Substances and Disease Registry oral minimal risk levels (MRLs) (ATSDR, 2001)
- California Environmental Protection Agency (CalEPA) cancer potency factors (CalEPA, 1999)
- EPA health assessment documents (U.S. EPA, 1986, 1987, 1998a).

A.4 References

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